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Abstract

Faculty of Engineering
Department of Mechanical Engineering

Doctor of Philosophy

Novel compression fracture specimens and analysis of photoelastic isotropic points

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Compression fracture specimens are ideally suited for *miniaturization* down to tens of microns. Fracture testing of thermal barrier coatings, ceramics and glasses are also best accomplished under compression or indentation. Compression fracture specimen of finite size with constant form factor was not available in the literature. The finite-sized specimen of *edge cracked semicircular disk* (ECSD) is designed which has the property of constant form factor. The novel ECSD specimen is explored further using weight function concept. This thesis, therefore, is mainly concerned with the design, development and geometric optimization of compression fracture specimen *vis a vis* their characterization of form factors, weight functions and isotropic points in the *uncracked* geometry.

Inspired by the Brazilian disk geometry, a novel compression fracture specimen is designed in the form of a semicircular disk with an edge crack which opens up due to the bending moment caused by the compressive load applied along its straight edge. This new design evolved from a set of photoelastic experiments conducted on the Brazilian disk and its two extreme cases. Surprisingly, normalized mode-I stress intensity factor of the semicircular specimen loaded under a particular Hertzian way, is found constant for a wide range of relative crack lengths. This property of *constant* form factor leads to the development of weight function for ECSD for deeper analysis of the specimen.

The weight function of a cracked geometry does not depend on loading configuration and it relates stress intensity factor to the stress distribution in the corresponding uncracked geometry through a weighted integral. The weight function for the disk specimen is synthesized in two different ways: using the conventional approach which requires crack opening displacement and the *dual form factor* method which is newly developed. Since stress distribution in the *uncracked* specimen is required in order to use weight function concept, analytical solution is attempted using linear elasticity theory.

Since closed form solution for stresses in the uncracked semicircular disk is seldom possible with the available techniques, a new semi-analytical method called *partial boundary collocation* (PBC), is developed which may be used for solving any 2-D elasticity problem involving a semi-geometry. In the new method, part of the boundary conditions are identically satisfied and remaining conditions are satisfied at discrete boundary points. The classical stress concentration factor for a semi-infinite plate with a semicircular edge notch re-derived using PBC is found to be accurate to the *eighth* decimal.

To enhance the form factor in order to test high-toughness materials, *edge cracked semicircular ring* (ECSR) specimen is designed in which bending moment at the crack-tip is increased significantly due to the ring geometry. ECSR is analyzed using finite element method and the corresponding uncracked problem is analyzed by PBC. Constant form factor is found possible for the ring specimen with tiny notch. In order to avoid varying semi-Hertzian angle during practice and thereby ensure consistent loading conditions, the designs are further modified by chopping at the loading zones and analyzed.

Photoelastic *isotropic points* (IPs) which are a special case of *zeroth order fringe* (ZOF) are often found in uncracked and cracked specimens. An analytical technique based on Flamant solution is developed for solving any problem involving circular domain loaded at its boundary. Formation of IPs in a circular disk is studied. The coefficients of static friction between the surfaces of disk and loading fixtures, in photoelastic experiments of three-point and four-point loadings, are explored analytically to confirm with experimental results.

The disk under multiple radial loads uniformly spaced on its periphery is found to give rise to one isolated IP at the center. Splitting of this IP into a number of IPs can be observed when the symmetry of normal loading is perturbed. Tangential loading is introduced along with normal loading to capture the effect of the composition on formation of IPs. Bernoulli's lemniscate is found to fit fringe order topology local to multiple IPs. Isotropic points along with other low fringe order zones including ZOF are ideal locations for material removal for weight reduction. Making a small hole in the prospective crack path at the IP location in the uncracked geometry might provide dual benefits: 1. Form factor enhancement; 2. Crack arrestor. Thus, this thesis describes experimental, theoretical and computational investigations for the design, development and calibration of novel compact compression fracture specimens.

Key words: Semicircular photoelastic disk, Hertzian load, Stress intensity factor (SIF), Weight function, Partial boundary collocation, Stress concentration factor (SCF), Flamant solution, Photoelastic isotropic point (IP)